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Monitoring the structural integrity of a flexible riser during a full-scale fatigue test

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ABSTRACT

Flexible risers are presently seen as an attractive alternative to their rigid counterparts in the offshore oil exploration industry, mainly because of their relatively simpler mounting and transportation. However, the complex multi-layered structure which guarantees high flexural compliance is not favorable for inspection with most non-destructive testing (NDT) techniques, which makes structural integrity evaluation difficult. Initial efforts concentrated on the search for a single technique which would ensure reliable detection of armor failure, but recent studies have shown that the safest approach may be to take advantage of the redundancy obtained when different instruments are combined. This work presents results of a full-scale dynamic loading test of a 6 m-long section of a flexible pipe with end-fittings which was instrumented with a range of sensors. Of these, measurements of torsional angle variation, axial displacement and Acoustic Emission were selected for a direct comparison. A detection pattern is observed during forced rupture of the wires of one of the outer armor layers, and reliable identification of events is possible when information from the three techniques is combined.

1. Introduction

Flexible pipelines are layered structures capable of resisting torsion, tension, internal/external pressure, and of deforming under bending loads [1]. In the type of tube considered in this work, where the layers are not bonded together, such mechanical behavior is made possible by a system of metallic armors: an inner carcass which conducts the internal product, a pressure armor which ensures resistance to axially symmetric loads, and two layers of helical metal strips which are counter-wound around the interior structures. While these confer the mechanical characteristics of the structure, polymeric layers prevent friction between the metal layers, seawater ingress and internal fluid leakage, and a thicker external layer protects the pipe from contact or wear damage [2]. Fig. 1 shows the structure of a riser similar to the one tested in this work. Of particular importance is the integrity of the armor layers since these may cause total collapse of the pipeline or tear-off of the softer layers and consequent leakage of the internal product [3]. Considerable levels of stress concentration in the vicinity of the end fitting which connects the pipeline to the oil rig make this a region which is particularly prone to fatigue related failure [4]. Damage in the vicinity of the water level may also occur due to contact with other risers or elements of the platform [5]. Monitoring of the integrity of the riser in the near-connector region is therefore important to ensure continuity of production and safe operation.

Many studies can be found in the literature on testing and monitoring of steel cables or wire ropes [6–9]; similarly to flexible pipes, cables are designed to withstand great traction loads, and their end-fittings are also often built by introducing their termination in epoxy-filled metallic sockets [10]. However, the flexible pipe which is the subject of the present study is considered to be a far more complex structure. Firstly, its multilayer design (described above, see Fig. 1) makes inspection and monitoring significantly more difficult. Furthermore, differently from conventional steel cables, the wires in these pipes have a considerably larger cross-section area; this, associated with the considerably hard and textured microstructure which results from their manufacturing processes, leads to important fracture mechanics issues. The wires are highly susceptible to small marks and pits, which can easily cause crack nucleation; propagation mechanisms are those found in fragile materials (mostly quasi-cleavage), which makes failures occur almost instantly once the critical flaw size, which is remarkably small, is reached. Ruptures of these wires cause structural instability and re-balancing of loads, which in turn causes friction between the unbroken wires and the debris and sharp edges of the broken ones; these effects can lead to rapid progressive failure

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